

AN INTELLIGENT PLANNING AND SCHEDULING SYSTEM FOR THE HST SERVICING MISSIONS

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ABSTRACT

A new, intelligent planning and scheduling system has been delivered to NASA-Goddard Space Flight Center (GSFC) to provide support for the up-coming Hubble Space Telescope (HST) Servicing Missions. This new system is the Servicing Mission Planning and Replanning Tool (SM/PART). SM/PART is written in C and runs on a UNIX-based workstation (IBM RS/6000) under Motif.

SM/PART effectively automates the complex task of building or rebuilding integrated timelines and command plans which are required by HST Servicing Mission personnel at their consoles during the missions. SM/PART is able to quickly build or rebuild timelines based on information stored in a Knowledge Base (KB) by using an Artificial Intelligence (AI) tool called the Planning And Resource Reasoning (PARR) shell. After a timeline has been built in the batch mode, it can be displayed and edited in an interactive mode with help from the PARR shell. Finally a detailed command plan is generated. The capability to quickly build or rebuild timelines and command plans provides an additional safety factor for the HST, Shuttle and Crew.

Key Words: Hubble Space Telescope, HST Servicing Mission, planning, scheduling, AI, expert system.

1. INTRODUCTION

HST Servicing Missions are Shuttle missions which are expected to occur every three years to upgrade or replace failed HST

components and to help the HST function to its fullest extent over its 15-year mission lifetime. SM/PART helps HST personnel generate "integrated timelines" and "command plans" that describe the activities and detailed procedures to be performed by the HST, Orbiter, Orbiter Crew and ground systems during the HST Servicing Missions. SM/PART has been built upon AI/expert system technology that has evolved through several expert systems delivered to NASA-GSFC (McLean *et al*, [1]).

1.1 The ERBS System

In 1987, the ERBS-TDRSS Contact Planning System (McLean *et al*, [2]) was delivered to the Earth Radiation Budget Satellite (ERBS) Flight Operations Team at NASA-GSFC to generate requests for communications support from the NASA Tracking and Data Relay Satellite System (TDRSS). This system was written in C and implemented on an IBM PC/AT.

The ERBS system is able to use external scheduling environment data and scheduling heuristics to automatically build a schedule of TDRSS requests. After a schedule is built, a graphical timeline is displayed so that users can edit the schedule in an interactive mode, while obtaining "expert" help from the system.

The ERBS system is able to generate a 1-week schedule of TDRSS requests in a few minutes, compared with several hours which were required by the superseded manual method. The ERBS system has been used steadily since its delivery. Also, the ERBS system has been modified and enhanced

several times to meet changing requirements. These changes were easily made because of the AI technology used in the system (McLean [3]).

1.2 The EPPS

In 1991, the Explorer Platform Planning System (EPPS) was delivered to the Extreme Ultra-Violet Explorer (EUVE) Flight Operations Team at NASA-GSFC (McLean *et al*, [4]). The EPPS uses much of the AI/expert system technology from the ERBS system. Like the ERBS system, the EPPS uses a KB to store scheduling heuristics and an AI shell (PARR) to build schedules in both the batch and interactive scheduling modes. As with the ERBS system, the EPPS uses alternative scheduling strategies to perform conflict resolution in addition to more traditional conflict avoidance techniques (McLean *et al*, [5]).

The EPPS provides several enhancements to the ERBS system. First, the EPPS runs on a UNIX-based workstation with X-Windows/Open-Look. Also, the EPPS schedules several types of EUVE mission support activities, in addition to TDRSS service requests which the ERBS system schedules. Finally, the EPPS uses an Ethernet to electronically receive resource data from the Flight Dynamics Facility at NASA-GSFC, receive planning data from EUVE Investigators at the University of California at Berkeley, exchange TDRSS schedule data with the Network Control Center at NASA-GSFC, and send sequences of EUVE command procedures to the Command Management Facility at NASA-GSFC.

1.3 SM/PART Overview

Now, a new, planning and scheduling expert system, SM/PART, has been built and delivered to NASA-GSFC (Johnson *et al*, [6]). SM/PART not only uses AI/expert system technology from the ERBS and EPPS systems but also provides several enhancements. For example, the SM/PART user interface was built with the help of Motif. The "look-and-feel" of this user-

friendly interface follows the OSF Motif Style Guide.

This paper focuses on two aspects of the SM/PART system which allow SM/PART to effectively automate the process of building or rebuilding integrated timelines and command plans for the HST Servicing Missions. These two aspects are strategic planning and tactical planning.

Strategic planning, as used in this paper, refers to the process of identifying and entering the complex heuristics that are used during tactical planning to put events on a timeline. To help SM/PART users develop and capture the strategic planning data, SM/PART provides powerful on-screen editing capabilities for Data Bases (DBs) and KBs. Data set configuration files allow users to define the specific DBs and KBs that are required to build each particular timeline and command plan. More features of SM/PART strategic planning are described in Section 2.

Tactical planning refers to the process of actually placing external scheduling environment data and HST events (activities and comments) on a timeline. For tactical planning, SM/PART uses the PARR shell to build timelines in either an automatic (batch) scheduling mode or an interactive scheduling mode. More features of SM/PART tactical planning are described in Section 3.

Users are able to build/edit HST Servicing Mission integrated timelines in an interactive scheduling mode with "expert" help from PARR. In this interactive scheduling mode, SM/PART provides graphical displays of timelines where objects on the displays are actively linked to specific DBs and KBs. Figure 1 shows a sample of a section of an HST integrated timeline.

Two basic types of HST Servicing Mission scheduling objects displayed on HST integrated timelines are "activities" and "comments." As these objects are edited

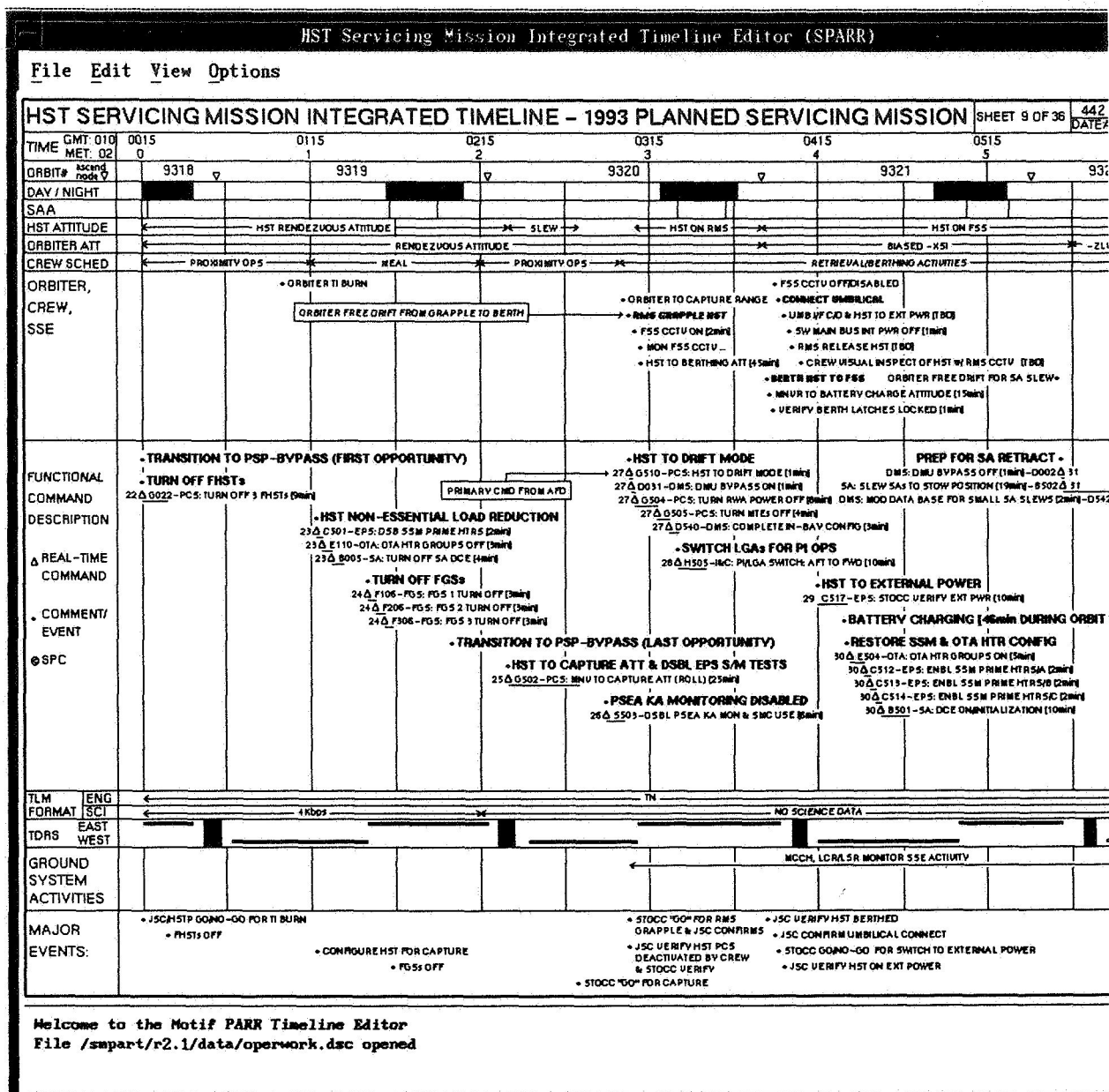


Figure 1. SM/PART Integrated Timeline Section

during an interactive scheduling session, the definitions of these objects in the Event Definition KB are automatically updated.

In addition to HST activities and comments, integrated timelines display several types of scheduling environment data including:

orbit data, orbital events data, HST/Orbiter attitude data, Orbiter/Crew activities, telemetry format data, TDRSS data, ground system activities and major events. Some of this scheduling environment data, such as orbit data, is obtained in electronic form from external sources and cannot be changed

by HST Servicing Mission personnel. Other types of scheduling environment data, such as ground system activities, are entered directly into DBs by HST Servicing Mission personnel and can be changed as needed. Eventually, most of these separate types of scheduling environment data are merged into a single Merged Resources DB before being used to build an Integrated Timeline display.

After a timeline has been built, detailed command procedures (Procs) associated with each scheduled HST timeline activity can be retrieved from a Proc Definition DB and used to automatically build a command plan. A command plan provides the detailed information required by HST Servicing Mission personnel at their operations consoles during an actual mission.

SM/PART also provides users with a hierarchical menu system for overall system control functions and access to UNIX-based utilities for editing ASCII files and performing system and file management functions such as saving, deleting, backing up, restoring and protecting files.

2. STRATEGIC PLANNING

HST activities are defined by users via Activity Event Definition (AD) Forms that contain slots for several types of data items. Some of the items on an AD Form such as "AD number," "AD title," "sequence number," "event type," "display type" and "duration" are relatively simple items. Other items on the AD Form such as "start event," "constraints" and "alternative strategies" are relatively complex. For these complex items, several linked "push-button" and/or "pop-up" menus are provided to make it easier for the users to enter the items. Examples of specific options provided for entering these more complex types of data items are described below.

The "start event" item on the AD Form has four linked data fields with "push-button" or "pop-up" menus so that users may easily

specify the conditions for an activity start time. By selecting menu options, the user may specify that an activity should start when a second (specified) event or resource starts or stops. Also, the user may specify a plus or minus "off-set" for the activity start time relative to the start or stop time of the second event or resource.

The "constraints" item on the AD Form has four linked data fields with "push-button" or "pop-up" menus to allow the user to enter complex constraints or rules for activities. Using these menus, the user can specify that an activity occur when a second specified event or resource occurs or, alternatively, avoid the second event or resource. Also, the user can enter plus or minus off-set times for the various options selected.

The "alternative strategies" item on the AD Form provides various possible alternative scheduling strategies to try, when there is a scheduling conflict. These options include trying to schedule the activity just before or just after a conflicting event, or trying to schedule an activity during the resource window that occurs just prior to or just after the resource window where the scheduling conflict occurs.

HST "comments" represent another major type of HST event that is scheduled. Comments are put into the Events Definition KB via a Comment Event Definition Form that has a structure similar to the Activity Event Definition Form just described.

To make it easier for users to set up sequences of activities for a command plan, SM/PART provides users with a Sequence Definition Form. This form allows the user to define items such as "sequence number," "sequence title," "sequence description," "initial conditions," "duration," "ADs in each sequence," and "special AD ordering instructions."

To make it easier for users to enter the detailed procedures which are required to build command plans, Proc Definition

Forms are provided. These forms allow users to enter procedure information such as: the specific procedures that are to be performed by operations personnel for each AD, the effects of each procedure, the duration of each step/substep, and the actions expected in space and throughout the ground system.

3. TACTICAL PLANNING

To build a timeline, PARR first reads information from the Merged Resources DB and Event Definition KB. The Merged Resources DB provides data that effectively defines the initial scheduling environment while the Event Definition KB provides the event definitions and scheduling heuristics that are used by PARR to place events on the timeline during the scheduling process.

Next, events are placed on the timeline in a batch mode. As each HST event (activity or comment) is considered for placement on the timeline, PARR dynamically allocates an internal frame structure to represent the event and uses the (current) scheduling environment data and the strategic planning data to find a place for the event on the timeline. If there are no conflicts, the event is put on the timeline and the scheduling environment and Event Definition KB are updated. If resources are not available or if constraints are violated, then alternative scheduling strategies are used to try to resolve the conflict. If there is a scheduling conflict that cannot be resolved then a prominent "VIOLATION" message is written in the Event Definition KB.

After a timeline has been built in the automatic scheduling mode, the timeline can be displayed on the terminal screen. This graphical timeline can be edited in an interactive scheduling mode with expert scheduling assistance from PARR. Interactive scheduling and editing are possible because all of the objects on the timeline are closely connected to specific DBs and KBs and PARR is constantly active.

For example, if the user clicks on an activity with the mouse and "drags" it to a new, valid position, then the Event Definition KB is automatically updated. If the activity is dragged to a place where a scheduling constraint is violated then a prominent "VIOLATION" message will be displayed on the screen.

After a satisfactory timeline has been developed, a command plan providing detailed command procedures for each timeline activity can be automatically generated. This command plan can be automatically synchronized with its corresponding timeline if changes in either the command plan or the timeline are made. A graphical "What-You-See-Is-What-You-Get" print of a command plan can be generated for HST personnel to use at their terminals during on-going missions.

4. SUMMARY

In this paper, the AI/expert system capabilities of SM/PART have been discussed from the perspective of strategic planning and tactical planning.

From the strategic planning perspective, complex event definitions and scheduling heuristics may be easily generated and stored in a strategic planning KB. Information in this strategic planning KB is used by PARR to control the automated scheduling processes in both the batch and the interactive scheduling modes.

From the tactical planning perspective, "intelligent" scheduling capabilities are provided by the PARR shell and a graphical integrated timeline. PARR is able to use scheduling environment data from the Merged Resources DB, strategic planning data from a strategic planning (Event Definition) KB and detailed command procedure data from the Proc Definition DB to effectively automate the process of building HST Servicing Mission timelines and command plans.

The capability to quickly build or rebuild HST Servicing Mission timelines and command plans provides a safety factor for the HST, Shuttle and Shuttle Crew in case unexpected events occur during the mission.

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REFERENCES

1. McLean, D., Tuchman, A., Johnson, J., Yen, W., Page, B., Bogovich, L., Burkhardt, C., Broseghini, T., Klein, S., McIntyre, J., Dao, H., Littlefield, R., and Potter, W., 1992, "Software Reuse in Spacecraft Planning and Scheduling Systems." In *Spaceops 92 - Proceedings of Second International Symposium on Ground Data Systems for Space Mission Operations*, (in press), Nov. 16-20, Pasadena, CA.
2. McLean, David R., Littlefield, Ronald G. and Beyer, David S., 1987, "An Expert System for Scheduling Requests for Communications Links between TDRSS and ERBS." In *Telematics and Informatics*, Vol. 4, No. 4, Pages 253-261, Pergamon Journals Ltd.
3. McLean, David R., 1991, "Maintaining an Expert Planning System: a Software Tools Approach." In *Institutionalizing Expert Systems: a Handbook for Managers*, Pages 91-98, Prentice Hall.
4. McLean, David R., Page, Brenda J. and Potter, William J., 1990, "The Explorer Platform Planning System: an Application of a Resource Reasoning Shell." In *Proceedings of First International Symposium on Ground Data Systems for Spacecraft Control*, Pages 195-200, Darmstadt, FRG, June 26-29.
5. McLean, D., Page, B., Tuchman, A., Kispert, A., Yen, W. and Poter, W., 1992, "Emphasizing Conflict Resolution Versus Conflict Avoidance During Schedule Generation." In *Expert Systems with Applications*, Vol. 5, Pages 441 - 446, Pergamon Press Ltd.
6. Johnson, J., Tuchman, A., McLean, D., Kispert, A., Bogovich, L., Burkhardt, C., Page, B., Littlefield, R., Potter, W., and Ochs, W., 1992, "HST Servicing Mission Planning and Replanning Tool." In *Proceedings of the World Space Congress-43rd Congress of the International Astronautical Federation*, August 28-September 5, Washington, DC.